IVERINE FLOW OBSERVATIONS AND MODELING:
Sensitivity of Delft3D River Model to Bathymetric Variability.

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LONG-TERM GOALS

The goal of our effort is to understand riverine fluid dynamics through in situ field observations and model validation.

OBJECTIVES

The primary objects are to: 1) establish the river flow response to horizontal (e.g., river width variations, bends, groins, etc.) and vertical bathymetric variability (e.g., channels and shoals, bars and dunes) with GPS-equipped surface drifters, dye sensors, an Unmanned Surface Vehicle (USV), and an Unmanned Underwater Vehicle (UUV) in varying river reaches that are charateristically different; and 2) validate Delft3D river flow model with these unique observations and subsequently examine the sensitivity of Delft3D river flow model to bathymetric variability in general under a wide range of forcing conditions using an ensemble approach.

APPROACH

The key element of our effort is to establish the sensitivity of river flow to (changes) in the bathymetry. To that end, we propose to collect a number of unique data sets at two characteristically different reaches with the Kootenai River, ID, which will be used to study the flow dynamics of rivers and to validate the Delft3D model for river flow.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2011	**N/A**	**-**

4. TITLE AND SUBTITLE
IVERINE FLOW OBSERVATIONS AND MODELING: Sensitivity of Delft3D River Model to Bathymetric Variability.

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Oceanography Department Spanagel 327c Naval Postgraduate School Monterey, CA 93943

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
FY10 Annual Reports of S & T efforts sponsored by the Ocean Battlespace Sensing S & T Department of the Office of Naval Research., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**7**	

WORK COMPLETED

We (MacMahan, Reniers, Swick, Brown, Thornton, Tuggle, Ashley, Rynne, and Cowen) collected various measurements on two characteristically different reaches in the Kootenai River, ID in August 2010. During our efforts, we have collaborated with Todd Holland at NRL and Jon Nelson at the USGS and Lisa Emery at QinetiQ. The braided reach (Figure 1) is a shallow (<3m) gravel river with flow velocities up to 2 m/s. We deployed stationary catamarans with downward facing ADCPs at various locations within this reach for approximately 15 minutes to obtain the mean vertical velocity profile. We deployed a frame instrumented with a 4m lagged coherent electromagnetic current meter array, single ADV, and custom 2 MHz Acoustic Doppler Current Profiler (ADCP) head to measure coherent structures at various locations within the braided reach for a minimum duration of two hours per location. We performed an intensive steady-state dye study in a 30m x 3 m channel to evaluate transverse mixing. 10 NPS and 6 QinetiQ drifters were deployed in the same dye channel. Bathymetric surveys were performed by a person walking with a GPS-equipped backpack and with an echosounder-equipped electric kayak. The meandering reach (Figure 2) is a deep (~10m) channel with flows around 0.5m/s located downstream of the braided reach. Two autonomous vehicles were used to describe the mean velocity profiles within this reach. In addition 40 NPS drifters and 6 QinetiQ drifters were also deployed in this reach.

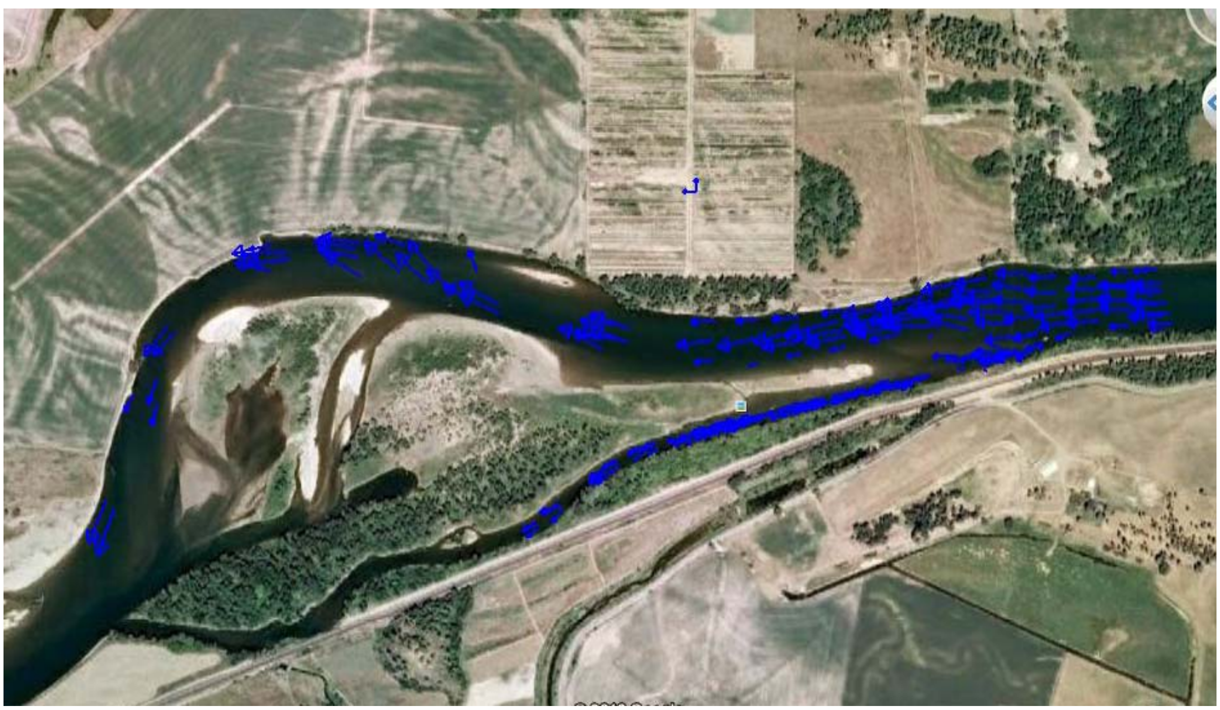

Figure 1. Surface velocity vectors from 15-minute averaged ADCP observation from stationary mini-catamarans overlaid on a Google Earth image of the meandering reach of the Kootenai River, ID. 0.5 m/s velocity scale plotted on the land north of the channel

Figure 2. Surface velocity vectors from 10-minute averaged ADCP observation when the USV was station-keeping overlaid on a Google Earth image of the meandering reach of the Kootenai River, ID. 0.5 m/s velocity scale plotted on land.

RESULTS

We are currently organizing and quality controlling the various datasets. Preliminary inspection of the data indicates that the experiment was highly successful.

3D Flow Structure

Two different AUV platforms: SeaRobotic unmanned surface vehicle (USV) and YSI/Oceanserver Technology IVER-II unmanned underwater vehicle (UUV) were used to measure the 3D velocity structure in the meandering reach. The USV has dual-propellers navigating with GPS and was able to station-keep to within 1 m for 10 minutes at various locations within the reach in order to obtain the 3D velocity field. Obtaining a statistically confident estimate of the mean velocity profile requires an appropriate time-interval to average instrument noise and environmental fluctuations. It has been previously proposed that 10 minutes is an adequate time interval when using an ADCP in a river. Preliminary results show that a shorter time interval is adequate, which would allow for increased spatial coverage. Surface velocity vectors are shown in Figure 2. The UUV has a station-keeping capability when at the surface, but owing to its single propeller, it operates best by performing slow (0.2-0.35m/s) moving transects. Since the UUV is moving in a system that is spatially non-homogenous, additional errors in the mean velocity profile can be introduced due to spatial variability. An evaluation of the velocity profile quality, current measuring performance and minimum averaging time interval requirements is being evaluated for each platform, including the appropriate mission

planning considerations for riverine observations. In addition, velocity time requirement minimums from stationary measurements in high-turbulent riverine environments obtained upstream in the braided reach will be evaluated.

River Mixing

Six fluorescent Rhodamine dye releases were conducted in a 30 m wide, 500 m long, and 2 m deep relatively straight reach in the Kootenai River, ID on 12-16 August 2010. The study reach contained a number of natural channel features, such as a pool-riffle sequence and bank irregularities, which influence transverse mixing. The dye was released at a constant rate for one hour from a kayak fixed in the center of the channel. River discharge was steady and all releases were conducted in the morning hours to avoid diurnal wind effects. Vertical dye concentrations and velocity profiles were measured near the source and at four downstream locations: 25m, 100m, 300m and 500m. In addition to the stationary observations, two different roving dye sampling schemes were performed to increase the spatial dye concentration resolution. The first sampling scheme consisted of 5 evenly-spaced dye sensors being slowly moved upstream. The second scheme consisted of 3 dye sensors moved transversely across the channel at various streamwise channel locations (Figure 3). These observations provide the horizontal and vertical extent of the dye plume and the spatial and temporal variability of the dye concentration. Local flow structures, produced by the separation of flow over riffles and bank irregularities, strongly control the observed local concentration distributions. A 1D analytical and the Delft3D numerical model will be used to assess the relative importance of turbulent diffusion and local flow structure on predicted spatial dye concentrations.

In addition, diffusivity estimates will be determined for GPS-equipped drifters, which were released in both reaches.

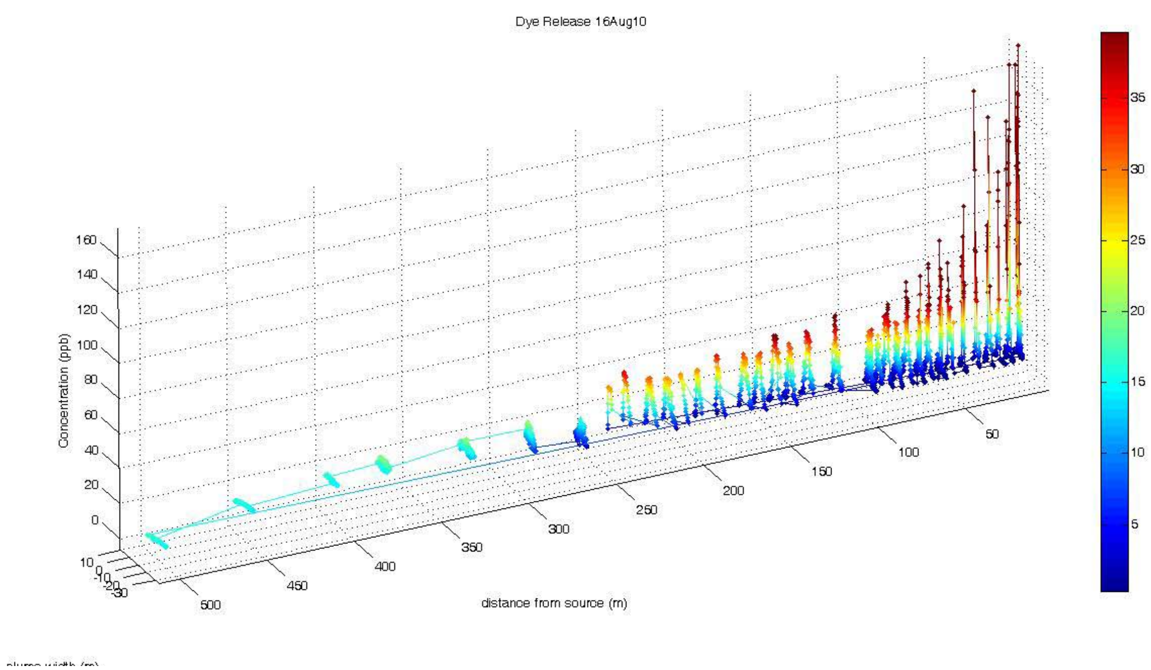

Figure 3. Spatial plot of dye concentration described from the source. Concentration colorscale shown to the right. Note the Gaussian shape of the cross-channel dye concentration estimates.

Coherent Structures

The frame was deployed in river water depths which varied from 0.6 to 1*m* with 0.5 to 1.5 *m/s* velocities. It was also deployed in the smaller channel used for the dye-experiments, near riffle pools, and on the lee of river obstructions. The lagged spacing of the six ECMs was set to resolve coherent motions from up to 8m in length. The ADCP was fitted with a custom head to measure the along beam velocities in all three axes, with a sampling frequency of 1 Hz, 35*cm* bins, with a maximum range of 10*m*. The upstream beam is used to describe the coherent structures in the stream-wise velocity. An iterative maximum likelihood estimator is used to evaluate the streamwise wavenumber-frequency spectrum. The coherent structures measured by the ECM array and ADCP are comparable in both wavenumber and frequency space, validating the use by the new ADCP head (Figure 4). Turbulent scales measurements from the 32 Hz sampled ADV decay with a slope of -1 and are comparable to the ADCP and ECM estimates. Our unique approach provides spatial measurements in river reaches (depths) previously not examined. The flow structure as a function of river feature, bed roughness, and flow velocity will be described in the stream-wise and lateral directions.

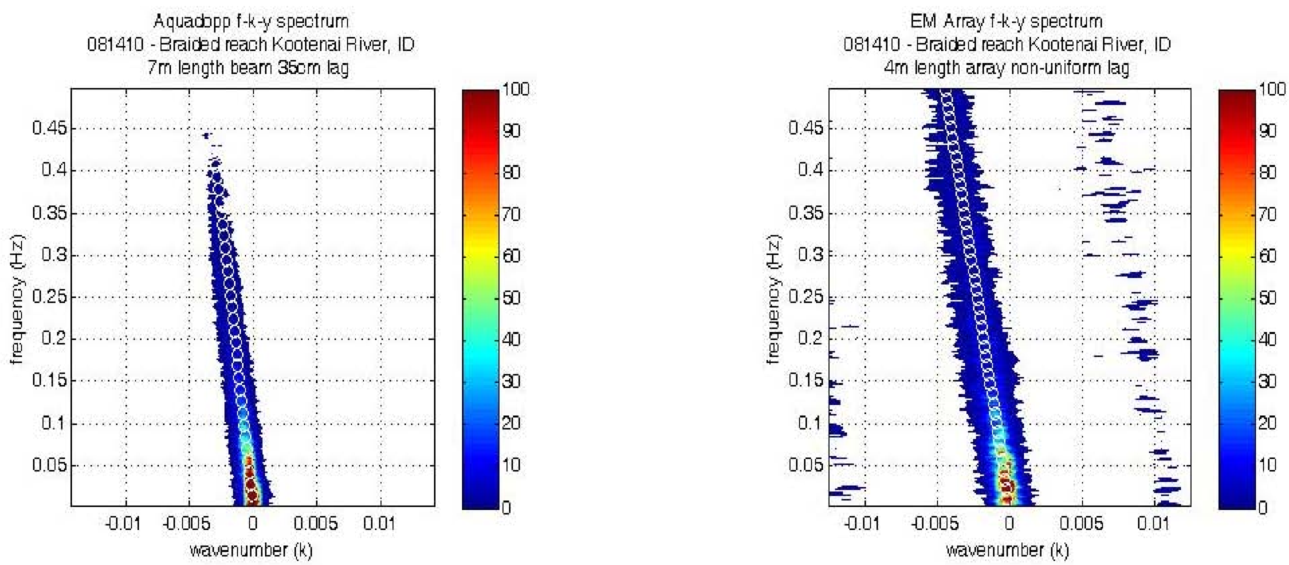

Figure 4. Frequency-wavenumber spectra for the streamwise velocities using custom ADCP head (left) and lagged electromagnetic current meter array. White circles overlaid on top represent the advected current. Coherent structures are similar between systems deployed at the same time.

DELFT3D modeling

A three-dimensional (3D) hydrodynamic model, *Delft3D*, is used to simulate flow for the meandering and braided reaches of the Kootenai River. There are three separate model domains: a large domain braided reach, a smaller domain “braided channel” and a model of the meandering reach, representing the different flow regimes and corresponding velocity scales. Model resolution of the braided reach, braided channel and meander reach was: 10, 3.5 and 20 meters respectively, with 5 vertical levels. Using field observations of bathymetry, water-surface elevation and discharge as boundary conditions, the flow field is calculated. Model skill was computed by comparing simulated velocity magnitudes with 20 min mean velocities measured at 14 cross sections on the meander reach with the USV. The magnitude model skill of 0.80 shows good comparison to the observed flow patterns (Figure 5).

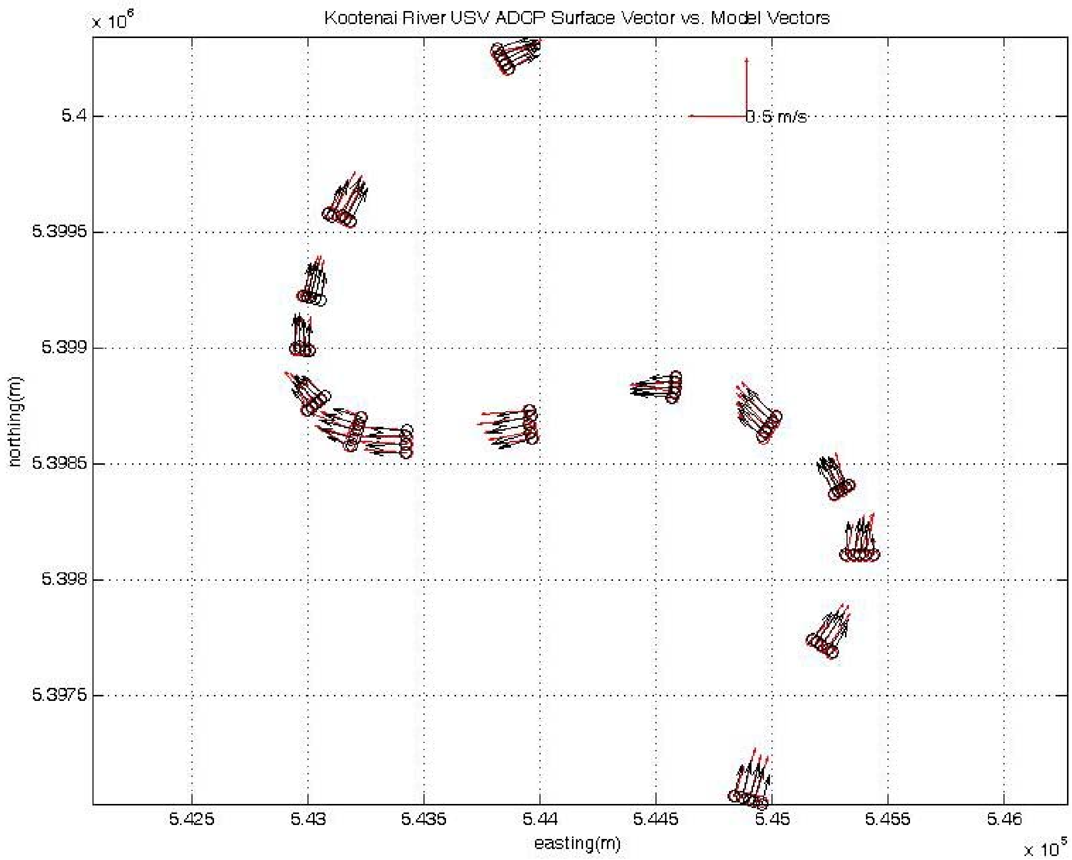

Figure 5. D3D (black arrows) and measured (red arrows) mean surface velocities for the meandering reach of the Kootenai River, ID, shown in Figure 2.

IMPACT/APPLICATIONS

The observation are important for understanding riverine processes by providing high-quality data for numerical model validation.

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